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BIOPHYSICAL INVESTIGATIONS ON THE INHALATION OF RADIOACTIVE AEROSOLS*

From the Max Plank Institute of Biophysics, Frankfurt on Main
(Professor Dr. B. Rajewsky, Director)

* Dedicated to Professor Dr. H. Langendorff on his 60th birthday

by Professor Dr. A. Schraub

Forschritte der biologischen
Aerosol-Forschung-Jahren 1957-1961, pp 317-334

In the lecture you have just heard, Dr. Herbst reported to you in detail on the contamination of the environment by radioactive fission products from atomic tests. As a result of this contamination, the entire population of the world is exposed to increased radiation; the resumption of nuclear tests on a larger scale than hitherto is liable to lead to increasing danger from radiation. The effect of this radiation essentially consists of two parts involving different mechanisms. First, we have an external radiation effect which is caused by the gamma-irradiating fission products which are deposited on the ground; second, we have an internal effect which develops because radioactive nuclides are taken into the human body on the one hand through food and drinking water and on the other hand through inhaled air. As we have seen, internal radiation, due to fission products ingested with food, is by far more serious here.

As a result of nuclear tests, vast amounts of fission products are released into the atmosphere and stratosphere and after a period of time return to earth in the form of fallout; on the other hand, we are trying very hard to prevent radioactive substances from escaping in operating our peaceful atomic energy program and in running our nuclear reactors. The regulations on the protection of the population against such radiation are so strict and the fines are so heavy that both the producer and the consumer of radioactive substances are doing everything they can to prevent accidents. Very highly developed automatic filtering systems stop even the very last traces of radiation; and if this should no longer be possible for technical reasons, then the particular substances are diluted so that there will be no danger to man or animal.

Of course, the protection of people working with nuclear reactors, "hot laboratories," and other nuclear facilities is much more difficult because these people must handle radioactive substances as part of their jobs. But here too we can protect our people by training them very carefully, by taking a number of safety measures, and by getting everyone to observe regulations governing the handling of equipment and substances; as a result, we find that there is no major exposition to radiation during normal operation. But even in case of unforeseen emergencies, danger from radiation can be controlled or avoided; on the other hand,

despite all precautions, there is always a possibility that gaseous or aerosol-form radioactive substances can escape in limited areas and can be inhaled without being spotted (Muth, H. and A. Schraub (32)).

Apart from these accidents, we can in some cases not prevent room air from revealing a small amount of contamination. This applies above all to our uranium and thorium mines and processing enterprises. Of course, the law must allow for a certain amount of occupational hazard for people working in such plants, so that the criteria here will be less strict than we must have them for the protection of the population as a whole. To protect our health, we must make sure that the "maximum permissible concentrations" of radioactivie nuclides in the air will be so determined that there will "reliably" be no danger to man. In addition we must know when we have this "safety" factor; ever since the start of our work with radioactive substances, our main concern in all radiation-biological research laboratories throughout the world has been the determination of this maximum permissible concentration. We cannot go into the difficulties encountered in estimating the significance of the various individual factors which play a role here, such as life of the particular nuclide, type and energy of emitted radiation, type of incorporation, etc.

In our case, it is our task to determine the boundary value of the concentration of radioactive substances in room air so that people will be able to work in this air during working hours or however long they must stay there -- and in the extreme case of course for a whole lifetime -- without there being any kind of damage to health. The standards for the population as a whole must be established even lower because in this case we must also consider the genetic consequences. For some very obvious reasons we of course cannot make experiments with human beings; we must therefore find other methods of determining the foundations for our estimates of these boundary values; I would like to show you tonight how any kind of knowledge, no matter how modest, may help us in increasing our reliability in the determination of these limits. It is precisely this problem of the inhalation of radiation-containing air which, almost in a classical fashion, shows us how we have been trying to get the needed information by various methods.

The first indication of course is furnished for us here by nature herself. You all know that the earth's crust has a uranium and thorium content which varies, depending on geological conditions. These elements are the basic components of the two most important natural radioactive decay series (figures 1 and 2), each of which develops a gaseous intermediate component, the so-called emanation, while all other members are metals. As a consequence, this emanation (Radon and Thoron) can spread from the place where it originates in the earth toward the earth's surface and into the air itself. This is the origin of the ever-present natural "contamination" in atmospheric air; near the ground, it is about 10^{-13} c/l for both emanations. In this radioactive atmosphere, man has been living for hundreds of thousands of years, apparently without suffering any damage.

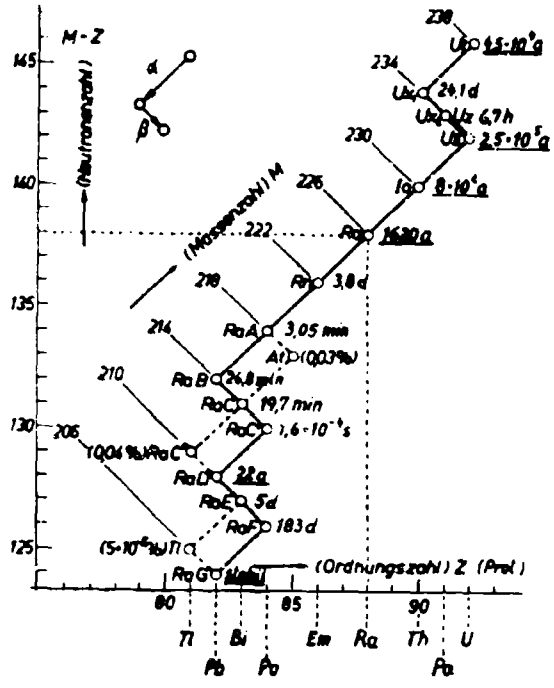

Figure 1. Decay scheme of the U-238 series: abscissa -- atomic number; ordinate -- neutron number. (The diagonal arrow shows the increasing mass number of the terms running in a direction opposite to the alpha decay.) Particularly long half-life periods (> 1a) have been underlined. The decay stages shown in dashed lines do not play a role in our considerations here because of their small probability.

Key: (a) (neutron number)
(b) (mass number) M
(c) (atomic number) Z (prot.)
(d) stable

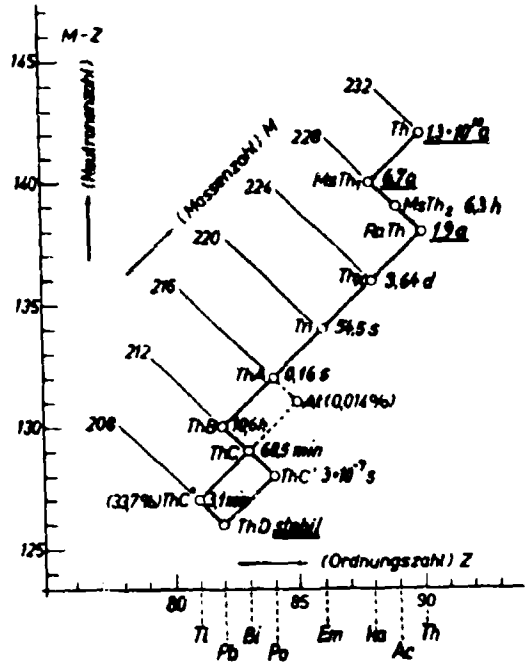

Figure 2. Decay scheme of the Th-232 series (for explanation, see caption, Figure 1).

The counterpart to this -- an air space with considerably higher Radon concentration which quite obviously is bound to have some sort of damaging effect on people living and working in it -- would be the air in the mines at Schneeberg and St. Joachimsthal. These mines are located on the German and Czechoslovak side of the Erzgebirge Mountains; in the past, there were silver mines here and later on, after the silver veins gave out, various ores (Schneeberg) and uranium (St. Joachimsthal) were mined here. The men in this area have been making a living as miners for centuries although it had always been said that the "air in the mines destroys the lungs of the miners." After a miner has been working in the mines here for about 20 to 25 years, that is, below ground, he gradually experiences increasing difficulty in breathing until he finally is unable to continue working underground. A few years after he has been thus disabled, he dies of consumption.

In 1879, long before radioactivity was discovered, Haerting and Hesse (7) published their obduction findings on 20 miners in the German section of the area; about 75% had "lumphosarcoma of the lung," a diagnosis which later was changed to "primary carcinoma of the lung." At the time, the mines were under Austrian administration on the other side of the mountain; the Austrian authorities were unable to confirm these findings with regard to their miners. About 40 years later, Marg. Uhlig (34) tackled this problem again for the Czechoslovak Mine Administration. Several years later, the new chief of the Radium Institute in St. Joachimsthal, Mr. Pirchan (24), was able to obtain the same results on the basis of his own investigation; Czechoslovak President Masaryk set up a commission which was charged with investigating this entire problem.

In 1936, the then "Committee for Cancer Control" created a subcommittee under the direction of Dr. Brandt which was charged with studying this problem. X-ray examinations on miners were made by Saupe, Buckup, and Heiner and the sections were made by Hueck. The biophysical aspects, particularly the determination of the mine status, were handled by Rajewsky (the author participated in this investigation).

The results of this investigation, in brief, were the following: It was very difficult to make a diagnosis on the basis of an X-ray; on the other hand, obduction findings essentially confirmed the findings of earlier years. Table 1 shows the results of investigations made by Heiner on 58 deceased miners.

TABLE 1. SECTION FINDINGS (DR. HEINER) ON 58 MINERS IN ST. JOACHIMSTHAL AREA

Cause of death	Number of Deaths
Carcinoma of respiratory organs	27
Heavy dust contamination of lung	13
Lung tuberculosis	12
Other illnesses, accidents, suicide	6

The Radon concentrations -- in agreement with earlier measurements (Behounek (13, 14)) -- were thus between 10^{-10} and 10^{-8} 8 c/l (Table 2).

TABLE 2. RADON CONCENTRATION IN MINE AIR IN ERZGEBIRGE MINES

Name of Mine	Radon Concentration in 10^{-10} c/l
Schneeberg district	
Neujahr mine	1.5 to 16
Weisser Hirsch mine	12 to 25
Schrot mine	6 to 28
Beust mine	11 to 42
Siebenschlehen mine	7 to 550
Johanngeorgenstadt district	8 to 24
St. Joachimsthal district	
St. Edelleut mine	0.4 to 15
Einigkeit mine	2.2 to 35
Werner mine	1.8 to 50

The dust in the mine air proved to practically inactive so that -- out of all the various possibilities for the development of Schneeberg mining sickness (radioactive dust, arsenic hydride, algae, etc.) which had been discussed earlier -- only the possibility of increased Radon content was most probable.

The next thing that had to be done was to prove that sufficiently long activity of the breathing organism in a Radon-containing atmosphere actually leads to the changes that had been found in the respiratory tract. In a series of laboratory experiments using mice, Rajewsky and associates (26, 27, 28, 29, 31) succeeded in producing such changes in the respiratory tract of the animals. The animals lived without interruption in airtight inhalation chambers, which were correspondingly air conditioned and which contained constant Radon concentrations, until they died. The weight and blood condition of the animals were constantly checked and tissue changes in the respirator tract of the deceased animals were examined. As was to be expected, it turned out that the average life expectancy of the animal series decreases as the Radon concentration increases. It is particularly important here to realize that tumor formations in the respiratory tract could be observed only in those animal groups which lived in the lowest Radon concentration used (about 10^{-6} c/l) and whose average life duration was about 200 days. At higher Radon concentrations, that is to say, in case of shorter lifetime, there was apparently not enough time for the development of a tumor.

Table 3 shows the result of the pathological-histological investigations. (The pathological-histological investigations were conducted under very difficult wartime conditions by Kahlau. Recently,

the preparations of Hug and Unnewehr were again examined thoroughly.) Out of a total 36 animals, the following findings were obtained: 2 pavement epithelium carcinomas, 9 adenomas, 3 malignantly deformed adenomas, 2 malignant blastomas of lymphoid character, 2 fibromas, and 2 thyroid adenomas.

TABLE 3. BREAKDOWN OF TUMOR CASES AS A RESULT OF CONTINUED INHALATION (1.5×10^{-6}) BY SURVIVAL DURATION (MICE)

No. of Animals	Survival	No. of Animals with lung reports
6	0-100 days	1
14	100-200 days	2
6	200-300 days	3
7	300-400 days	3
3	Over 400 days	3

Due to lack of time, the volume of available animal material is rather limited; nevertheless, Table 3 shows that the frequency of tumor increases along with the time during which the animals resisted the effect of Radon. Of the 16 control animals, which under otherwise identical conditions lived in Radon-free cages for about the same periods of time, only one had a lung adenoma.

Apart from the limitation mentioned above and apart from the continuing doubt about the applicability of such results to man, there is one more consideration which we must take up: The Radon concentrations used in the animal experiments were higher by a factor of larger than 100 than those in the mines. On the other hand, one might cite the argument that the time in the case of the miners was about 30 to 40 as long. But we have a second argument here which we are now going to discuss in greater detail. A few years after the war, the same institute resumed its investigations with radon (Rajewskiy, Schraub, Aurand, Jacobi, Reinholz, Wirth, Belloch-Zimmermann (1, 2, 3, 15, 16, 17, 18, 19, 21)); this was done with the intention of studying the behavior and distribution of the noble gas Radon in the organism; this gas was to be studied both after oral administration (aqueous Radon solution) and after inhalation of Radon-containing air. The idea was to try to calculate the radiation resulting here on the basis of the Radon concentrations found in the individual organs and tissues.

In this connection, investigators had a chance to make successful use of the method mentioned by Rajewskiy (29) which makes it possible to render the distribution of the gas Radon measurable and visible even in microscopic ranges. To this end, we kill the animal to be examined and we immediately place it in liquid air where it remains until the Radon has decayed completely (after about 6 weeks). By then, the

gaseous Radon has turned into the no longer diffusible RaD (Pb-210) (see Fig. 1). Now we can prepare the organs and tissues we are interested in here after the body of the animal has thawed out; then we can determine the RaD content, for instance, by means of the 47 keV-gamma line of the RaD; this Radon content is after all strictly proportional to the Radon content at the time the animal is placed in liquid air.

Similarly, we can prepare histological sections (of the entire animal or individual organs) ans we can make the macroscopic and microscopic distribution visible with the help of autoradiography. The degree of blackening, caused by the beta radiation during the decomposition of RaD and RaE (Bi-210) is then a measure for the Radon concentration which was originally present in this place. As the preparation gets older, the last radioactive after-product of this series (Po-210) increases gradually so that even its alpha-radiation contributes to the bargaining.

Figure 3. Photographic image of a 70-μ section through a frozen rat below the thorax; the rat had inhaled Radon-containing air for 10 minutes prior to its death. The heavily blackened places correspond to fatty layers with high Radon content.

Figure 4. Autoradiographic image

Figures 3 and 4 represent the macroscopic photographic, respectively, autoradiographic image of the section surface of a rat dissected perpendicularly to the axis of the body; this rat had inhaled Radon-containing air in a concentration of 5 x 10^{-9} c/cu m for a period of 10 minutes before its death. Tracer radiography is particularly suitable for microscopic ranges because here we can calculate the original Radon concentration in each place along the section on the basis of the area of origin and the density of the alpha traces (Figure 5).

Figure 5. Tracer-autoradiography (stripping method) of a stomach section (stomach entrance). During subjective observation through the microscope we can easily determine the place of origin of every alpha-trace by turning the micrometer screw. Most of the traces come from the mucosa and the stomach content.

The results of these investigations we had made and of the other investigations (Nussbaum and Hursh (23)), which were obtained by a different method, can briefly be summarized as follows: the chemically inert gas, as expected, does not undergo any selective enrichment in the organism which is caused by metabolism. Only the fat reveals a considerably higher solubility and thus an enrichment in Radon which may amount to as much as 20- and 30-times the value for the remaining soft tissue.

In the course of our investigations (Aurand and Schraub (1)) on Radon distribution after oral administration, we found quite clearly that the short-lived and long-lived after-rpoducts of Radon, introduced with the Radon solution, play a dominant role, depending on the age of the solution, in the extent to which the various organs and tissues are hit by radiation. We found confirmation for this in the results reported by Hollcroft and Lorenz (9, 10). In an analogous fashion, it would seem that similar considerations would also have to apply for inhalation; as a matter of fact, as we shall see right away, this should apply even more so here.

The intake of the noble gas by the breathing organism represents a satiation process which, after attainment of the solubility balance, is terminated; on the other hand, the intake of the decay products of the Radon, present in the air, involves a different mechanism. During every breath, the respiratory tract, like a filter, retains a certain portion of the inhaled radioactive nuclides on its surface; the amount of this portion depends on a number of factors; we remember this, of course, from the usual intake of aerosols. As a matter of fact, this is the same mechanism because these after-products generally are located right next to the air aerosol. An exception here is the aerosol-poor atmosphere of RaA into which Radon atom is converted in connection with its alpha decay. It exists as a single atom or single ion in the air space and there is very little probability that it will find an aerosol partner during its short average lifeti e (about 4.5 minutes).

From our experiences in dusty control we know that this continual collection, which theoretically would have to lead to unlimited deposit formation, counteracts the selfpurification mechanism of the respiratory tract. Insoluble particles are almost without exception transported back by the cilia apparatus of the bronchial branch and are then either expelled by coughing or are swallowed. The rest is phagocyted. Soluble particles, on the other hand, are either chemically bound (for instance, by proteins of local fixed cells) and are thus held in place or they get into the blood stream through resorption and are transported, depending on their chemical properties, into the various organs and tissues as a result of metabolism.

These considerations also apply to the inhaled after-products of Radon, whereby RaA assumes a special position for the reasons mentioned earlier. The accumulated nuclides either go the way of the carrier aerosol or, if this is possible (and here we need further investigation), they are removed from the carrier aerosol in the chemical environment of the bronchial secretion and can then continue to react chemically.

If these considerations were not correct, then it should be possible to make comparative experiments on animals, using aerosol-poor

air, on the one hand, and heavily aerosol-containing air, on the other hand; these experiments should enable us to establish the differing resorption which we must expect here. Above all, there would have to be certain consequences arising from the viewpoint of radiation protection. We found confirmation for these ideas (Aurand and Schraub (35)) in a memorandum by Bale and Shapiro (4, 5, 6) where these possibilities and their consequences for labor hygiene in uranium-containing mines and uranium processing facilities were pointed out. Theoretical considerations (Bale and Shapiro (6); Harley (8); Schraub, Aurand, and Jacobi (35, 17)) indicate that, under certain conditions, the radiation hitting the lungs for instance can, in the extreme case, be as much as a thousand times stronger if Radon-containing air is inhaled in balance with the after-products; this is in contrast to the case of inhalation of air with the same Radon concentration which however does not contain any after-products. However, we can expect greatly differing radiation amounts for an atmosphere that contains many after-products and an atmosphere that contains few if any after-products also for other organs and tissues of the organism on account of the previously described possibilities of resorption in the lung and in the stomach and intestinal tract.

On the basis of preliminary experiments (Aurand, Schraub, Jacobi (11, 18)) we made sure that, despite the short life of the partners found here (see Figure 1), it is still possible to prove their migration in the organism in connection with Radon inhalation; then we also succeeded in separating the direct resorption in the lung from the stomach and intestine resorption of the swallowed portion (Figure 6). During these investigations, we used the longer-lived ThB (Pb-212 with 10.6 hours half-life) from the Thorium series (Figure 2).

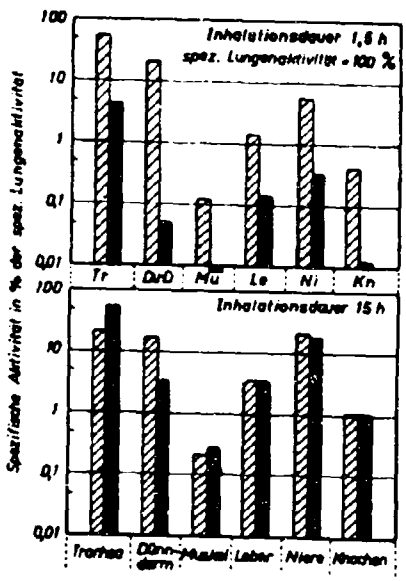

Figure 6. Activity distribution in rats with tied-up esophagus after inhalation of Th B. ■ Aesophagus tied up; ▨ Control.

Key: (a) specific activity in percent of these specific lung activities;
(b) duration of inhalation 1.5 hours;
(c) specific lung activity equals 100%;
(d) duration of inhalation 15 hours;
(e) small intestine;
(f) muscle;
(g) liver;
(h) kidney;
(i) bones.

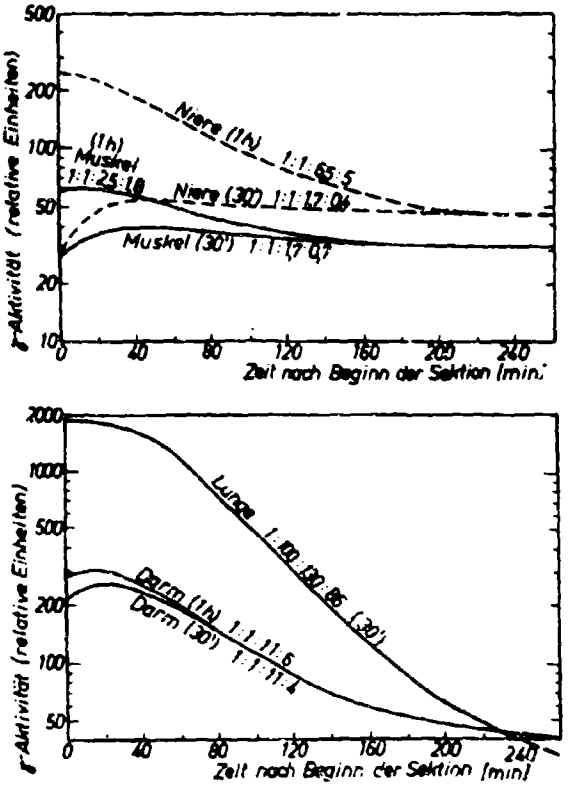

Figure 7a and 7b. Time record of gamma activity in various mouse organs after the animal has been in a Radon atmosphere containing very little in the way of after-products (1 : 0.6 : 0.1 : 0.02) for a period of half an hour and one hour. In case of balance in the air (1 : 1 : 1 : 1), that is, when we have a 1.6-fold RaA, a 10-fold RaB, and a 5-fold RaC concentration, the curves start at correspondingly higher initial values and then drop more abruptly toward the Radon values.

Key: (a) gamma-activity (relative units); (b) kidney; (c) muscle; (d) time after start of section (minutes); (e) lung; (f) intestine.

(I want to express my deep thanks to my former colleagues Dr. Aurand and Dr. Gerber for helping me with this difficult project.)

Studies on the behavior of after-products of Radon (Schraub, 20) are therefore not so easy to conduct experimentally because, due to the short lifetime, the preparation of the organs and tissues we are interested in here must be accomplished very quickly. Right after that, we must determine the time-wise activity of the organs by recording the gamma-emission of RaB and RaC. By analyzing this curve, we can calculate the content of the sample as regards Radon, RaA, RaB, and RaC at time zero (time of death). Figures 7a and b show an example of the time-wise activity for a number of organs of animals which lived in a Radon atmosphere having the following after-product composition. Radon: RaA: RaB: RaC = 1:0.6: 0.1 : 0.02. The graph shows the curves for ~30 and 60 minutes of inhalation. Here the end value, into which each curve runs, is a measure for the Radon content, while the amount and course of the curve in the beginning is determined by the series partner. (If we had a balance between Radon and its after-product or series-product, we would illustrate that with a straight line running parallel to the time axis; if the after-product were lower than this, we would have a curve rising from lower values toward the Radon end value. A drop of the curve from high initial values thus means that we have a strong excess of after-products.)

Here are the most important facts emerging from these experiments.

1. Quite apart from the fat, the values for the Radon content of the various organs and tissues do not differ greatly. This confirms the results of Nussbaum and Hursh and our own "freezing experiments."

2. The very high initial value for the lung quite convincingly shows the high deposit of after-products found on the lung.

3. After one hour of inhalation -- that is, when we have roughly a balance in the movement of after-products -- the other tissues also, in part contain considerable quantities of after-products.

4. Under the conditions of after-product enrichment in the air, discussed above, we get particularly high values for the content of after-products as far as the kidney and the stomach and intestinal tract are concerned. But this means that these organs are particularly hard hit by radiation. As far as the kidney is concerned, Morken (36) was able to prove this also quite recently.

Using this method, we are in a position to calculate the radiation load for each organ.

These investigations (the results were presented on the occasion of the "International Congress of Radiation Research" in Burlington, U.S., 11-15 August 1958) were conducted in the same inhalation chambers as the continuous inhalation experiments we mentioned earlier. But this means that the changes in the lung, in the case of our experimental mice, came about in an atmosphere which was almost completely free of after-products. On the basis of measurements taken in uranium mines (Tsivoglou, Ayer, Holaday, 33; Aurand, Jacobi, Muth, Schraub (unpublished)) we know that we must expect a considerably higher after-product content there; the short-lived RaA is always in balance with the Radon; the RaB, depending on the intensity of ventilation, reaches values of 60 and 80%; RaC reaches 30 and 50%. We can estimate theoretically how great the after-product accumulation would be in the respiratory tract and hence also in the other organs if the experimental animals in Table 3 had lived in such an atmosphere. Depending on the prevailing conditions, we can then calculate the radiation dose output which are higher by a factor of 10 to 100.

On this basis, we can assume with good justification that the changes in the lungs in our continuous experiment could have been achieved with correspondingly lower radon concentrations if the animals had lived in an atmosphere where the after-products were in balance. Of course, we cannot prove this assumption conclusively unless we repeat those continued inhalation experiments under the conditions mentioned. It would be desirable to conduct this experiment -- which of course requires a considerable expenditure in the way of time and personnel -- with a sufficiently large number of animals and to include it in our program.

We can experimentally confirm this assumption on the basis of the results of a number of short-term inhalation experiments which were conducted sometime ago for a different purpose. Figure 8 shows the results of these experiments (Schraub 20, Morken 12) in which the animals (mice) lived in Radon-containing air, at correspondingly higher concentration -- for a period of only 6-8 hours. The curve labelled "Rn" represents the survival time as a function of "Radon dose." The abscissa values are the product of the Radon concentration and the exposition time and give us a measure for the average radiation dose which takes effect. This curve was obtained in practically after-product-free Radon air. In comparison to this, we plotted two of our own (Schraub and Belloch 20) experimental points and three other points (Kushneva 22) from experiments which were made with a heavy content of after-products (near the balance value). We were able to do this in our experiments by cutting off

cage ventilation; by spreading the drying agent and the soda lime over a large area in order to eliminate CO_2; in this manner we obtained air conditioning effects with minimum convection. As a result, the developing decay products were separated along the page walls only in very small amounts, that is to say, most of them remained in the air. The results of these experiments can only be interpreted by saying that, if the radon concentration remains constant, the presence of the decay products in the air leads to a considerable shortening of the lifetime of the animals. In other words, this means the following: To get the same survival time, we only need one fiftieth to one one-hundredth of the radar concentration, if the experimental conditions are such that a radioactive balance can be established in the air. Applied to our continuous inhalation experiments, this would mean that our earlier assumption would be confirmed; the Radon concentration required for the production of the lung changes we achieved can be estimated at about 10^{-8} c/l, provided of course that this conclusion is also applicable to the changes that have occurred in the lung. But this brings us very close to the Radon concentration we can find in Table 2 for the uranium mines.

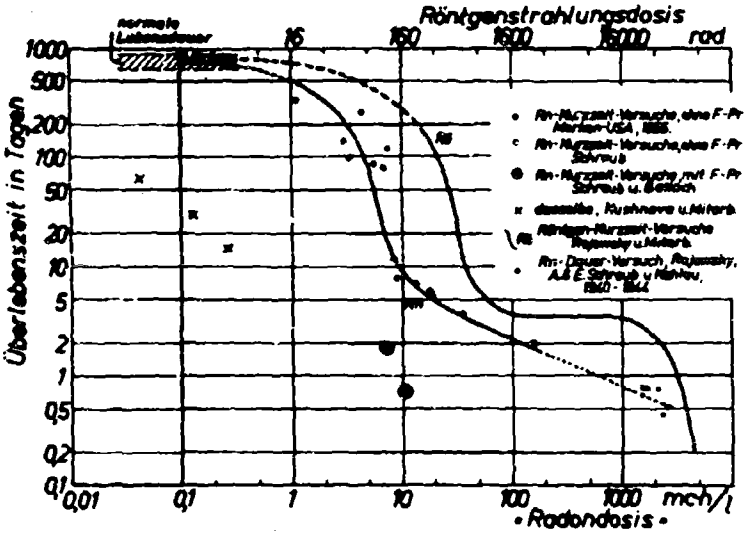

Figure 8. "Rn" curve. Effect of short-term (6-8 hours) Radon inhalation on the survival time of mice. (Atmosphere practically free of after-products.) The experimental points indicated by crosses and double circles were obtained in an atmosphere which was rich in

after-products (see text). The "Rδ" curve represents the analogous dependence when the entire body is irradiated with X-rays.

Key: (a) survival time in days; (b) normal lifetime;
(c) X-ray irradiation dose; (d) "Radon dose";
(e) Rn short-term experiments, without after-products Morken, US, 1955;
Rn short-term experiments, without after-products Schraub;
Rn short-term experiments, with after-products Schraub and Belloch;
same, Kushneva and associates;
Rδ X-ray short-term experiments Rajewsky and associates;
Rn continuous experiment, Rajewsky, A. and E. Schraub, and Kahlau, 1940-1944.

In conclusion we might make a few remarks on the question of the actual radiation doses. A rough estimate of the actually effective radiation dose in the respiratory tract of the miners at Schneeberg during a period of 25 years of work underground led to a value of approximately 20,000 to 30,000 rem; here, a value of 10 has been assumed for the relative biological effectiveness of the alpha radiation which, in this particular case, is practically the only kind of radiation that is significant. A similar estimate of the total radiation dose in the respiratory tract of animals with tumor used in the continuous experiments would give us a figure of approximately 30,000 rem. Of course, these estimates are rather uncertain so that this numerical agreement is not too significant. We could not make any definite statements until further animal experiments have been conducted under well-defined conditions.

In this article, we were trying to show how biophysical research is trying to compile material in order to determine the "maximum permissible concentrations" of radioactive substances in the air and to confirm or correct values that have been established earlier; the same also applies to the contamination of food and drinking water. In this connection it is interesting to point out the values for Radon concentration which are specified in the "First Radiation Protection Regulation" of 24 June 1960.

According to Appendix 2 of this regulation, the protection of people working in enterprises in which Radon can escape into the air calls for a working week of 40 hours in a Radon concentration of 3×10^{-11} c/l ($\approx 3 \times 10^{-8}$ μc/cu cm) as maximum value. If we assume an average value of c x 10^{-9} c/l for the air in the mines at Schneeberg and St. Joachimsthal, then the currently maximum permissible value would be 1/100 of this concentration. This safety factor of 100

is certainly adequate. Using the above value, we would get about 10 rem for this maximum value of the Radon concentration as radiation loan on the respiratory tract of people working in uranium mines and processing plants. However, we must remember that this estimate was made on the basis of the assumption of unfavorable conditions as regards the atmosphere in the mines (regulation, degree of enrichment of after-products in the air, size of particles of aerosol, etc.); therefore, this value is certainly on the safe side with the factor of 2. This represents a satisfactory experimental confirmation of the equivalent of the requirements in Article 25, Paragraph 3 (5 rem/a) with the Radon maximum concentration in the Appendix 2 of the Radiation Protection Regulation.

We now want to point out one more thing here. Article 34, Para. 1, specifies that air leaving controlled areas must not contain more than 10^{-12} c/l. This requirement is a little bit too strict if we consider that the normal concentration of Radon in atmospheric air is 0.3 and 3×10^{-13} c/l -- and if we can prove that there are areas in the world and that there are rooms in buildings of a certain type in which 10^{-12} c/l are by no means rare. It is to be expected that, sometime in the future, when we have more data, the competent authorities will suggest that this value be raised. Of course, the protection of man is an absolute top priority requirement. However, responsible radiation protection experts will not hesitate to raise maximum values which were estimated with excessive caution, so long as there are no other objections to this; on the other hand, the continued maintenance of these values will create almost insurmountable difficulties for further technical development and freedom of movement.

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Discussion

Bisa, Grafschaft:

Our Schneeberg lung cancer is evident proof for the toxic-synergistic effect of aerosols. We know that it was necessary after the war to employ new workers in various uranium mines, some of whom came from various sections of the country and had held different occupations in the past. Those workers who had been in the mines in the past, that is those who had absorbed dust in their lungs, and were not exactly ill as a result, were finished as far as mining is concerned after a few years. But those who were in the uranium mines for the first time held out for a longer period of time and did not reveal damage until after 12 or 13 years. These are the findings of the International Labor Office.